Measurement of Schumann Resonance at Kamioka

S. Atsuta[1], T. Ogawa[2], S. Yamaguchi[3], K. Hayama[4], A. Araya[2], N. Kanda[4], O. Miyakawa[5], S. Miyoki[5], A. Nishizawa[6], K. Ono[5], Y. Saito[5], K. Somiya[1], T. Uchiyama[5], M. Uyeshima[2], and K. Yano[1]

[1] Department of Physics, Tokyo Institute of Technology, 2-12-1, Oh-okayama, Meguro-ku, Tokyo, 152-8551, Japan
[2] Earthquake Research Institute, The University of Tokyo, 1-1-1, Yayoi, Bunkyo-ku, Tokyo, 113-0032, Japan
[3] Department of Biology and Geosciences, Osaka City University, 3-3-138, Sugimoto, Sumiyoshi-ku, Osaka, 558-8585, Japan
[4] Department of Physics, Osaka City University, 3-3-138, Sugimoto, Sumiyoshi-ku, Osaka, 558-8585, Japan
[5] Institute for Cosmic Ray Research, The University of Tokyo, 5-1-5, Kashiwa-no-Ha, Kashiwa City, Chiba, 277-8582, Japan
[6] Division of Physics, Mathematics, and Astronomy, California Institute of Technology, 1200 E, California Blvd, Pasadena, CA 91125, USA

E-mail: atsuta@gw.phys.titech.ac.jp

Abstract. On the stochastic gravitational-wave search, correlated noise in two or more gravitational-wave detectors can be a serious problem. Schumann resonance is the name of a standing wave of electromagnetic fields, which is one of the correlated noise sources for the second-generation gravitational-wave detectors. We measured the noise levels of the environmental magnetic field both inside and outside the mine of KAGRA site at Kamioka. In this letter, we report the result of the measurement and compare the amplitude of magnetic fields inside and outside the mine to find possible issues or gain of constructing a detector underground.

1. Introduction

One of the target sources of the second-generation gravitational-wave detectors (Advanced LIGO [1], Advanced Virgo [2], and KAGRA [3]) is the so-called stochastic gravitational-wave background (SGWB). The SGWB can be created from many uncorrelated and unresolved gravitational-waves, which contain the signals from astrophysical and cosmological events. Astrophysical sources include binary neutron stars [4], binary black holes [5], highly magnetized stars [6] and rotating neutron stars [7]. Cosmological sources are, for example, inflationary physics [8] and cosmic strings [9].

For the data analysis of gravitational-wave signals, a matched-filtering method is effective for a signal with theoretically predicted waveform [10]. The waveform of SGWB, however, cannot be predicted. A standard method for the analysis of SGWB is to cross-correlate strain data sets from two or more different detectors. Cross-correlating the data sets enables us to distinguish a signal-like noise from real gravitational waves since a noise is mostly local and is uncorrelated between different detectors.

While the first-generation detectors did not see any globally correlated noise, the sensitivity of the second-generation detectors is so high that such a small global phenomenon can create problematic correlated-noise [11]. One of the problematic global phenomena is Schumann resonance [12] [13].

Journal of Physics: Conference Series **716** (2016) 012020 doi:10.1088/1742-6596/716/1/012020

Schumann resonance is a standing wave of electromagnetic field, which occurs when a space between the surface of the Earth and the ionosphere makes a resonant cavity for electromagnetic waves. Schumann resonance is excited by lightnings that can be seen almost all over the world, and thus Schumann resonance can be seen any time from any direction. All the ground-based gravitational-detectors will then be exposed to a same Schumann resonance, except KAGRA, located underground, which might be differently affected by this phenomenon. It is important to measure Schumann resonance and compare the level inside and outside the mine.

2. Formalism

First we measure a magnetic field signal using coil sensors and collect time series data $m(t)$. We then Fourier transform the signal to obtain $\widetilde{m}(f)$ and calculate the power spectrum:

$$P(f) = \frac{2T}{N}\widetilde{m}^*(f)\widetilde{m}(f)\ . \tag{1}$$

Here N is the number of data, T is the sampling time ($T = 1/F_s$, where F_s is the sampling frequency) and t is time. In order to analyze the correlation of the signals obtained inside and outside the Kamioka mine, we also define coherence $coh(f)$:

$$coh(f) = \frac{|\widetilde{m_1}^*(f)\widetilde{m_2}(f)|^2}{|\widetilde{m_1}(f)|^2|\widetilde{m_2}(f)|^2}\ , \tag{2}$$

where $\widetilde{m_1}^*(f)$ means complex conjugate of $\widetilde{m_1}(f)$.

3. Method and Results

We used coil sensors PHOENIX GEOPHYSICS AMTC-30 magnetometers to measure the enviromental magnetic field at the KAGRA site. We set the coil sensors both inside and outside the mine with data loggers MTU-5A produced by PHOENIX GEOPHYSICS at each site. Continuous measurements with $F_s = 150$ [Hz], synchronized with GPS clocks, were performed. In a manner of the Magnetotelluric method, we placed two coil sensors in each location, one of which in the north-south (NS) and the other in the east-west (EW) directions. At the observation point outside the mine, we buried the coils about 20 cm deep in underground to avoid acoustic noise and so on. Inside the mine, as we were not able to cast a ditch, we placed and fixed the coils on the floor. The data was collected for about 30 hours. Since it was stormy and frequent spikes were found in the data set on the second observation day possibly due to frequent lightnings, we decided to use the data obtained on the first day only.

Figure 1 shows the median of the power spectrum of the magnetic field. Firstly we obtained data for 14 hours each day, and then we divided it in one-hour segments to calculate the power spectrum using DFT method. Since KAGRA was under construction during the daytime, we decided to use data obtained in the night-time to avoid noise caused by the construction work. We divided one-hour night-time data to 30-second segments and plotted the median of the power spectra.

Although Fig. 1 shows that the spectrum of the inside is higher than the outside, we do not know any clear mechanisms that promote Schumann resonance inside the mine. Several reasons can be considered for this increase: (a) calibration was not correct in some of the coil sensors, (b) the coil sensors did not work properly with the large amplitude noise, (c) the large amplitude noise raised the floor level of the spectrum. We will discuss (a) in Sec.4. We did not test (b). If (c) is the reason, a use of a certain window function in the calculation of the power spectrum would improve the problem, but we did not see any significant change.

Figure 2 shows the coherence between the signals inside and outside the mine defined in Eq.(2). Schumann resonance comes from a corresponding direction, which is determined by the direction of the

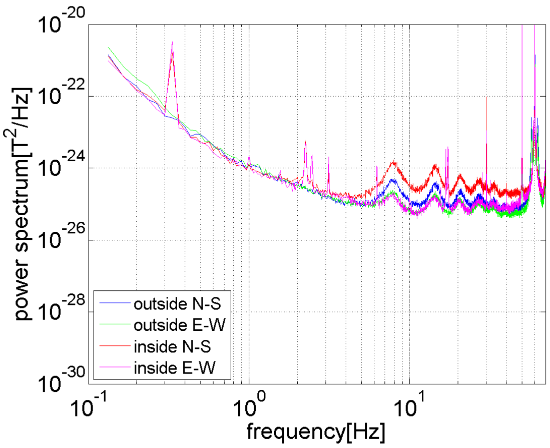

Figure 1: Median of the power spectrum of the magnetic field obtained in night-time. For all the data, Schumann resonance peaks appear at almost same frequencies (7.8 Hz, 14 Hz, $\cdots$) The peaks at 30 and 60 Hz are caused by the power line. The peak at 50 Hz appears only inside the mine, which can be from a power line for machines used inside the mine. Although some peaks were observed inside the mine, we do not refer their details since there existed a lot of unknown noise sources in the underground.

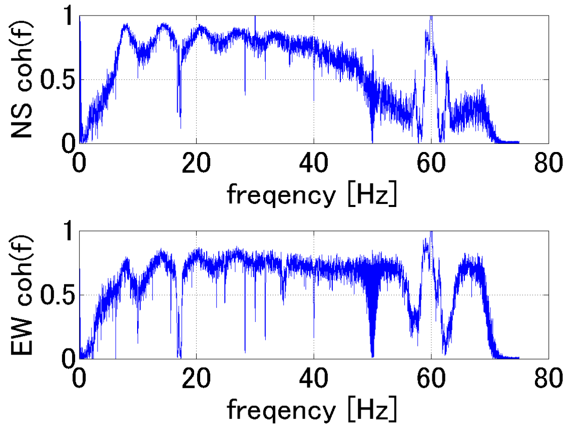

Figure 2: Coherence of the signal. At the frequency of Schumann resonance, high $coh(f)$ value indicates that the same resonance is observed both inside and outside the mine.

location of the lightning. High coherence indicates that the same Schumann resonance is observed both inside and outside the mine.

Figure 3 shows a histgram of the magnetic-field signal $m(t)$. The horizontal coordinate is the amplitude of the signal, and the vertical coordinate is the number of data with the corresponding signal. The histgram for the outside can be regarded as the Gaussian distribution with the almost zero mean, while that for the inside shows a magnetic-field signal at a certain frequency. This unknown signal has a large amplitude, which can come from the power line at 50 Hz that is seen in Fig. 1. This 50 Hz power line is much larger inside than outside. This signal could be the large signal we discussed for reasons (b) and (c).

4. Coils Test

One of the reasons we can consider for the higher level of the spectrum inside the mine may be a wrong calibration of the coil sensors. In order to check the calibration levels, we performed another measurement with these coil sensors in a magnetically quiet location: Mt. Kasagata in Hyogo prefecture.

At Mt. Kasagata, we measured a magnetic field in the same way as we did at Kamioka except for the direction of the coils. In order to measure a same signal, we placed the coils in the same direction but far from each other not to detect the magnetic signal from other coils.

Figure 4 shows the results of the simultaneous measurement. Almost no difference among the 4 coils was observed.

5. Conclusion

Schumann resonance was observed both inside and outside the Kamioka mine at the KAGRA site, and its amplitude was almost at the same level. This result means that Schumann resonance can be a problem for

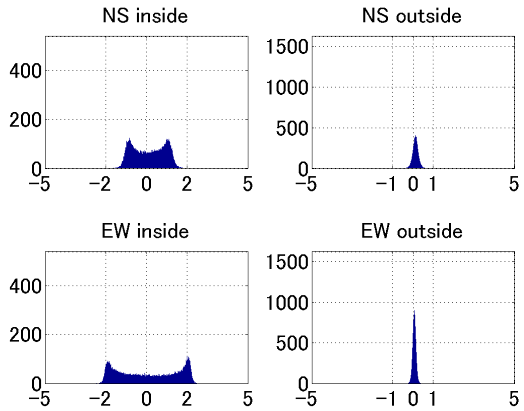

Figure 3: Histgram of each coil signal $m(t)$.The horizontal coordinate is the amplitude of the signal ($\times 10^4$), and the vertical coordinate is the number of data.

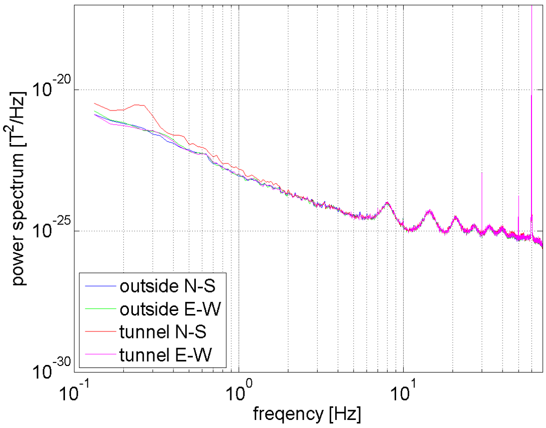

Figure 4: Magnetic median power spectrum calculated in the same way as in Fig. 1 under almost the same environment. No significant difference between coils can be seen in this figure. We concluded that the difference of calibration levels is not a problem in our measurement.

the cross-correlation method with data sets that contain KAGRA data. In fact, the power spectrum of the magnetic field inside the mine is higher than outside. We tried to find a reason for this. We checked the calibration levels by measuring the magnetic field in a quiet location but we did not see any difference. Since there were many artifacts made of iron, which has large magnetic permeability, inside the mine, they might have affected the magnetic signal obtained inside the mine.

Acknowledgments

We thank to Institute for Geothermal Sciences, Kyoto University by lending the coils we used in this letter. And we also thank to colleagues of Tokyo Institute of Technology and Osaka City University for helping our work. This work was supported by MEXT, JSPS Leading-edge Research Infrastructure Program, JSPS Grant-in-Aid for Specially Promoted Research 26000005, MEXT Grant-in-Aid for Scientific Research on Innovative Areas 24103005 and JSPS Core-to-Core Program, A. Advanced Research Networks.

Reference

[1] G. M. Harry for the LIGO Scientific Collaboration 2010 *Class. Quantum Grav.*, **27**, 084006
[2] F. Acernese et al., 2015 *Class. Quantum Grav.*, **32** 024001
[3] K. Somiya for the KAGRA collaboration, 2012 *Class. Quantum Grav.*, **29** 124007
[4] B. Allen, 2011 *Prog. Theor. Phys. Supp.*, **190**, 316
[5] X. Zhu, E. Howell, T. Refimbau, D. Blair, and Z. Zhu, 2011 *Astrophys. J.*, **739**, 86
[6] S. Marassi, R. Ciolfli, R. Schneider, L. Stella, and V. Ferrari, 2011 *Mon. Not. R. Astron. Soc.*, **411**, 2549
[7] T. Regimbau and J. A. de Freitas Pacheco, 2001 *A & A*, **376**
[8] B. Allen, 1988 *Phys. Rev. D*, **37**, 2078
[9] L. Sousa, and P. P. Avelino, 2013 *Phys. Rev. D*, **88**, 023516
[10] Jolien D. E. Creighton and Warren G. Anderson 2011 *Gravtitaional-Wave Physics and Astronomy* (New York: Wiley-VCH)
[11] E. Thrane, N. Christensen, and R. M. S. Schofield, 2013 *Phys. Rev. D*, **87**, 123009
[12] W. O. Schumann, 1952 *Zeitschrift fur Naturforschung A*, **7**, 149
[13] W. O. Schumann, 1952 *Zeitschrift fur Naturforschung A*, **7**, 250